THE EVALUATION OF THERMAL, ROOM ACOUSTICS AND DAYLIGHT PERFORMANCE OF OLD INDRAPURI MOSQUE IN ACEH BESAR, INDONESIA

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ABSTRACT

This paper aims at assessing the performance of thermal, room acoustics and daylight of the old Indrapuri mosque. Indrapuri mosque is located in Aceh Besar and built in the 12th century. The mosque is famous with the history of Aceh; therefore, it belongs to the cultural heritage object conserved by the government. After some decades, the facade has been maintained and conserved. However, some conservation steps were shifted from the principle ones such as using traditional techniques and materials. The data were collected using survey and mechanical measurement. The results show that some replacements cause some spatial discomforts such as higher indoor thermal performance. It is indicated in Olgyay's bioclimatic chart which also shows that the air movement should be increased to reach the comfort zone. The mosque acoustics performance has slightly high background noise, while the sound pressure level and reverberation time still meet the standard. The daylight remains good. This is shown when there is no electrical light is switched on during the day including daytime prayer i.e. Zuhr (1 pm) and 'Ashr (4 pm).

Keywords: *Old mosque, Thermal Comfort, Acoustic, Daylight*

INTRODUCTION

Indrapuri mosque (as shown Fugre 1) is an old mosque located in Aceh Besar district. The mosque was built on top of the base of a former 12th-century Hindu temple from the Hindu Kingdom of Lamuri of North Sumatra. When Islam came to Indrapuri, Sultan Iskandar Muda converted the Hindu kingdom to be Islamic. Later, the Indrapuri mosque was erected in the place of Hindu temple square, which is surrounded with stepping and magnificent views of nature (Disbudpar, 2015).

This mosque is rich with the history of Aceh province. It is a sacred place that has produced many Islamic scholars. As the mosque in Aceh was previously utilized for many purposes, the mosque was also functioned as a place for preparing the war strategic against the Dutch colonialism. Even more, it had become the center of governance of Aceh kingdom for a while when the Acehnese kingdom was dominated by the Dutch. However, the Dutch had dominated the Indrapuri mosque which had caused the removal of capital city from Indrapuri to Keumala. This mosque is also well-known with the coronation of Sultan Alaiddin Muhammad Daud Syah, who led Aceh from 1874-1903 AD.

Figure 1: Indrapuri Mosque from the Old to the Present

The total area of the mosque is 33.875 m^2, while the area of the worshipping place is about 15 x 15m. It has three tiered roofs, which are supported by 36 wooden columns. The roof was initially made from rumbia leaf which provides upper apertures for circulating out the hot air. The western pulpit was built continuously connected to 1.5 m height of stone fence surrounding the floor plan (Meuko, 2015). The open terrace with steps surrounding the mosque creates a magnificent view of the mosque. At the northern part of the mosque, the wooden tower stands which is believed to be previously functioned as a place for sounding azan. The wooden mosque was built with the wood pegs system. However, nowadays the mosque has been strengthened with nails especially in the roof construction.

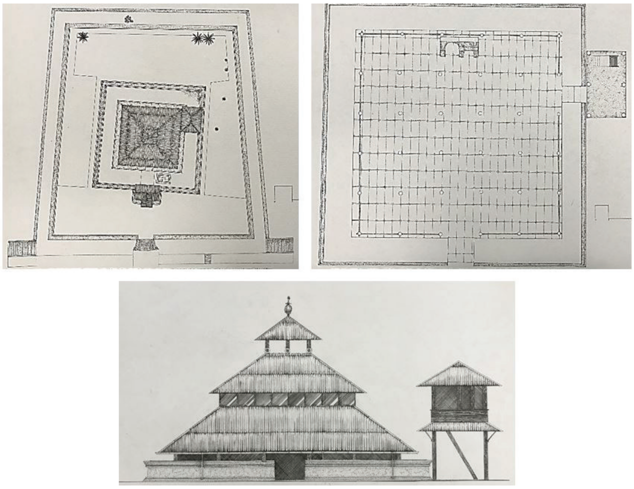


Figure 2: Site Plan, Floor Plan, Front View of Indrapuri Mosque
(Source: Author's document)

The tiered roof model of Indrapuri mosque, which is up to 12 m above the ground, looks like the traditional roof of some mosques in some other places in Indonesia. However, some scholars say that the mosque in tiered roof style firstly came from Aceh since Aceh was the first area where Islam initially spread in Indonesia. However, despite many interpretations of the shape of this roof, this kind of roof works well in tropics climate. Therefore, this type of mosque design is identified as Nusantara typical mosque. Even more the former Indonesian president 'Mr. Soeharto' initiated to build up to 999 mosques applying this style across Indonesia (Yayasan Amal Bakti Muslim Pancasila, 2013)

This mosque is one of the ancient mosques in Aceh which is highly preserved yet still function as the daily worshipping place for Muslims. However, some replacements were applied such as the roof which was converted to corrugated zinc sheet. The upper aperture between the tiered roofs was sealed with plastic fiber to protect the room from the rain splash. The floor has been plastered with marble which covers the umpak foundation causing the poles planted into the ground. At last, the stone wall was partially coated with cement. This study, therefore, assesses the thermal, daylight and acoustic conditions. This performance will benefit some recommendations to approach sustainable historic building conservation.

SPATIAL COMFORT AND MOSQUE

The mosque is a sacred place for worshipping (Al-Hamoud, 2009; Saeed, 1996), which serves as a place for Muslim to do their daily prayers , as a symbol of Islam as well as space for social gatherings, education, and community service (Kahera, et.al, 2009). There are many factors contributing to the shaping of the typology, design, and role of the mosque in a multicultural atmosphere (farrag, 2017). One of the factors is spatial comfort, which is required in a mosque for the presence of the solemnness to the worshippers (Al-Hamoud, 2009; Saeed, 1996). The spatial comfort in this study comprises good room acoustics performance such as good sound level pressure distribution and sufficient reverberation time; thermal comfort criteria; and adequate daylight provision. In addition, meeting the spatial comfort is also a way to conserve the energy in running the building. Acoustic performance inside the mosque is critical since good sound distribution would increase the solemnness of the worshippers in performing the prayer. In the mosque, the intelligibility of both speech and other sounds is extremely important, especially crucial for holy tones that must be both spacious and effective. Several acoustical parameters govern speech audibility, intelligibility, and spaciousness of sound. The parameters are usually employed in the acoustical analysis of mosques such as reverberation time, sound pressure level distribution and sound transmission index (Eldien et al., 2012).

Thermal comfort criteria in tropics, Indonesia refers to the formula of neutral temperature in Indonesia was developed by Karyono (2015), which indicates that the comfortable indoor temperature in Banda Aceh and its surrounding is specified in 23.40C- 29.70C (Sari, 2017). This condition is quite challenging to achieve due to high relative humidity (RH) and high air temperature (Ta). To get such comfortable thermal sensation, high air velocity is needed to reduce the relative humidity which is set comfortable at 35% to 70% (Evan, 1980; Humphrey, 1992; ASHRAE, 1992; Karyono, 1996; Szokolay, 1990). The effect of air movement is essential in increasing the efficiency of sweat evaporation and thus avoid discomfort due to moisture on the skin. In hot humid climate, the most proper air velocity for day comfort is in the range of 0.10 to 0.40 m/s and, indoor air velocities of 1.0 m/s are delightful and are acceptable up to 1.5 m/s, anything above that is considered unacceptable (Szokolay, 1990). This condition is included in Olgyay's bioclimatic chart, which provides the comfort zone that considers the air temperature, relative humidity, and air velocity. The higher air temperature, the higher the airspeed should be in order to reach the comfort (figure 8). As commonly known that the air can be circulated naturally through optimal apertures with the cross ventilation system. Good thermal sensation in tropics can also be obtained by the use of low conductivity materials and light colour which has little value of heat absorptance (Emmanuel et al., 2007; Sari et al., 2018).

Building design using daylight system is considered as an excellent passive lighting design. Daylight is lighting obtained from secondary sunlight source. It provides the best source which comfortably matches with human visual response (Arab et al., 2012). To measure the indoor lighting performance illuminance level is utilized. Based on the measurable scales shown in Table 1 the illuminance of the mosque should be minimally in scale five which is ranged from 200-499 lux, which means that the illuminance quantity is sufficient in getting details that are easy to see at normal brightness for reading. In the mosque, the worshippers do not only do salat or prayer, but they also recite Al-Quran which needs sufficient light.

Table 1: Measurable Scales of Lighting (Arab et al., 2012)

Scale	Illuminance (lux)	Level
1	0 - 19	Total darkness to dark
2	20 - 49	Do not demand a high visibility of the task (public areas)
3	50 - 99	Do not demand a high visibility of the task (orientation during short stop)
4	100 - 199	Do not demand a high visibility of the task (rooms not in permanent use and hallway brightness)
5	200 - 499	Details easy to see at normal brightness for reading or office area
6	500 - 999	Details difficult to see like intricate work for brightness
7	1000 - 1999	Task lighting for highly demanding work - extremely fine details like microelectronic assembly

8	2000 - 10000	Task lighting for highly demanding work - extremely fine details like special tasks in surgery (10000 lux is maximum brightness from sunlight to indoor area)
9	10001 - 100000	Outdoor area brightness (100000 lux is the maximum measurement)

RESEARCH METHOD

In order to evaluate the quantity and the quality of sound distribution inside the mosque, this study recorded sound pressure level, reverberation time and background noise. The acoustic condition was only measured for one day within the empty room. Omnidirectional speaker (NOR-223) was located in the center of the room which is 1.50m above the ground to represent the condition of standing speech. This speaker provided sound source for calculating the reverberation time (ISO3382) and sound pressure level. The measurement that was carried out on some spots (Figure 3) utilized ½ inch microphone as the receiver set on 0.85m above the ground which represented the sitting condition. Before the measurement, the tools were initially calibrated in order to get the correct results. After the measurement of reverberation time and sound pressure level, the background noise was also recorded using RTA 840 and calibrated microphone condenser to identify the room criteria. The tools measured the ambient noise of sound pressure level (SPL) which was also positioned 0.85 m above the ground.

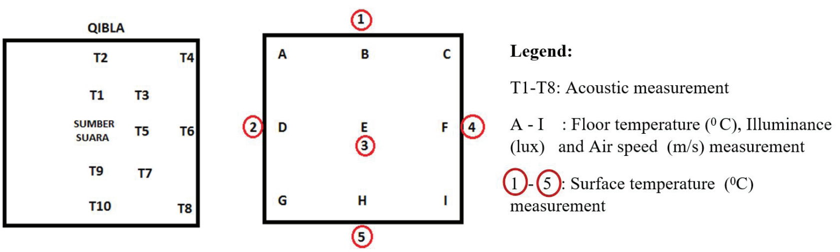


Figure 3: The Position of the Measurement

Thermal performance data were collected utilizing Heat Stress WGBT Meter–TM 188D. The thermal data included Globe temperature (Tg), Air temperature (Ta), and Relative Humidity (RH). Meanwhile, the air velocity was measured by using Anemomaster Model 6113. The surface temperature (0C) of the building envelope was recorded by utilizing Infrared Thermometer KW06-280, and at last the illuminance of daylight received inside the mosque (E) was measured using lux meter. The measurement was carried out for one day on May, 3rd 2018.

RESULTS

Acoustics Performance

a. Sound Pressure Level

The measurement was done by using the artificial sound source that was located in the middle. The even size and symmetrical form of the floor plan created the voice source which is 81,5 dB distributed evenly to all spots. The furthest voice has the SPL of 76,50 dB. The difference of sound pressure level which is less than 10dB of the sound source in every position of the rooms met the criteria, which means that SPL distributions are loud enough to be received by the listener against the background noise (figure 4).

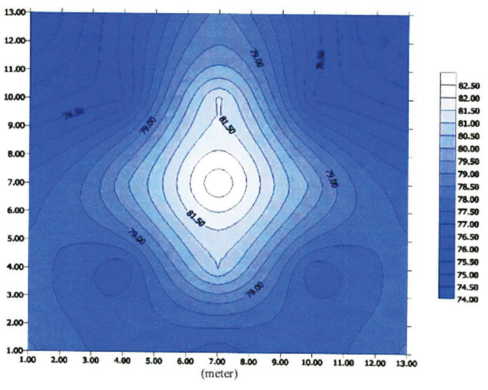
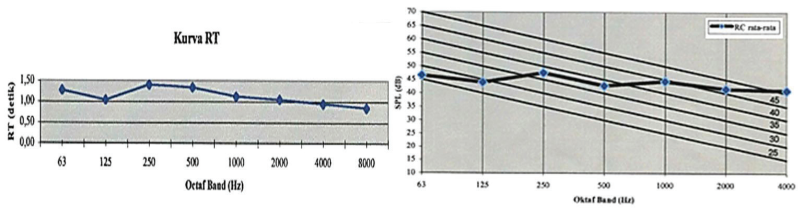


Figure 4: Sound Pressure Level Distribution in Indrapuri Mosque

b. Reverberation Time

The reverberation time (RT) curve (Figure 5.a) shows the uneven RT on every frequency for on octave band. It shows that the curve is increasing in low frequency (125 Hz- 250Hz), which is around 1.0-1.4 second, while in medium frequency the curve is decreasing down to 1.2 second and running down below to 1 second on high frequency (4000-8000Hz). This condition shows an optimal performance of speech room criteria, which also justifies an excellent performance of mosque design of Indrapuri Mosque.



a. b.

Figure 5: a. Reverberation Time Curve of Indrapuri Mosque b. RC Curve Showing the Back Ground Noise Inside Indrapuri Mosque

c. Back Ground Noise

The mosque is located slightly remote from the main street. In addition, it is surrounded by stepping walls. Thus, it should not have the background noise especially in the praying area. However, during the measurement, the zinc roof that was previously installed with rumbia leaf made some intermittence noise that is shown in Figure 4b. RC curve shows that the average value stands on RC-40 and 45 which is noted as slightly higher than recommended on background noise in worshipping place.

Despite the slightly high background noise due to the broken zinc sheet, the overall room acoustics performance shows that Indrapuri mosque works very well in giving adequate and sufficient comfort in listening activities. The mosque worshippers also mentioned that the priest gave the sermon without any loud speakers. This proves that such mosque form and size is an ideal design in delivering good room acoustics.

Thermal Performance

The thermal performance of Indrapuri mosque was indicated through the air temperature, globe temperature, relative humidity and the surface temperature of roof, wall, and floor. Figure 6 shows that the relative humidity fluctuating around 64 to 75% which is somewhat higher than the comfortable range of RH that is between 35% and 70%. Meanwhile, the average air and globe temperature run similarly which are about 310C. The average surface temperature of short stone wall and floor are also close to 310C. Even though Figure 6 shows that the zinc roof surface temperature is high up to 550C which is due to the thermal conductivity value which is about 116 (W/m K), yet the globe temperature is just close to the air temperature. This condition may be due to the large openings and the less building envelopes. The top aperture of the mosque is still left open which helps to circulate out the hot air from the top. However, if the roof is conserved by installing the leaf roof as the original material, the globe temperature will be probably comfortably reduced. In some studies evaluating the Acehnese traditional house, which still applies rumbia leaf as the roof material, the indoor thermal performance, that remain good have been conducted (Sari, 2010; 2017). Since the Acehnese traditional house is made from timber and leaf roof which is lightweight, the micro climate really influences the indoor thermal performance. In this case planting the surrounding with greeneries to provide shade to cool the micro climate.

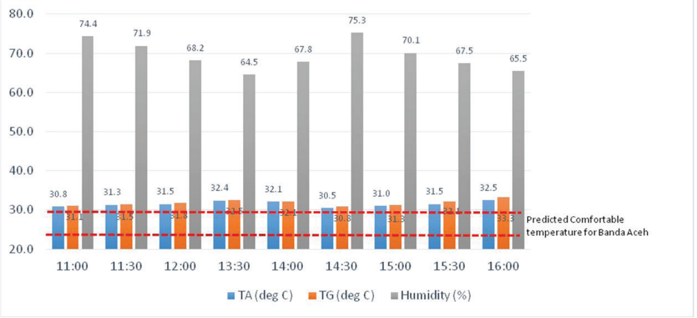


Figure 6: Temperatures and Relative Humidity Inside Indrapuri Mosque

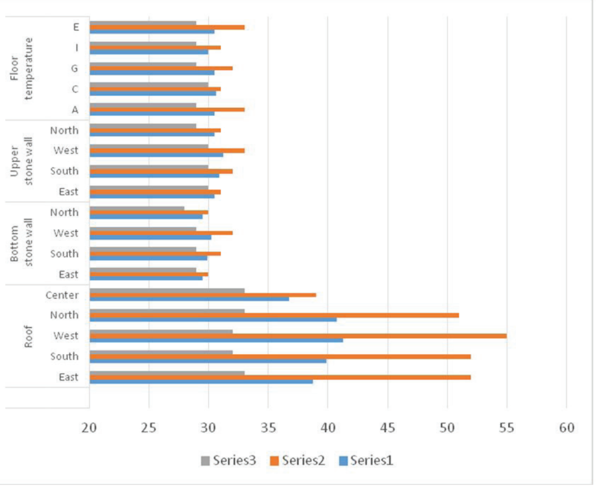


Figure 7: The Surface Temperature of Indrapuri Mosque Building Envelope

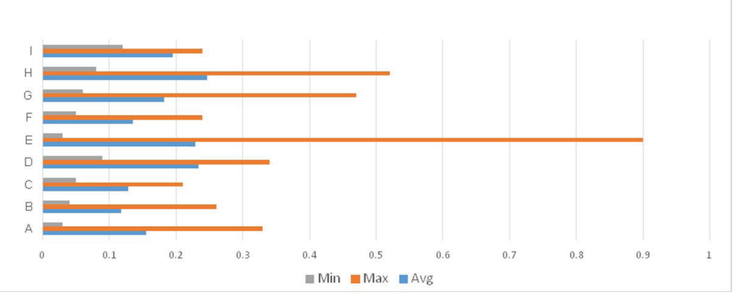


Figure 8: Air Velocity (m/s) Inside Indrapuri Mosque

Figure 8 shows that the air movement which is recorded 80cm above the ground is running on the average of 0,1-0,4m/s. The highest maximum value of the air speed is in zone E which is about 0,9 m/s. It is followed by zone H and G. Zone E is located in the center where it is directly connected to zone H, the main entry where no wall stands is distracting the wind.

Thermal Comfort Prediction

Based on the formula for predicting the comfort temperature in Indonesia, Karyono (2015) collected some thermal comfort studies in Indonesia and from those studies he found a regression equation of predicted comfort temperature (PCT) on the mean daily outdoor temperature as follows:

$$PCT = 0.749Td + 5.953 \ldots\ldots (1)$$

PCT is the predicted comfort temperature, and Td is the average daily outdoor temperature. The coefficient determination of R2 = 0.38 (r = 0.61), and the regression is significant at a 95% confidence level.

Table 2: Comfort Range of Banda Aceh

	Max(0C)	Min (0C)	Avg (0C)
Td	31,8	23,2	27,5
Tco	29,7	23,4	26,6

Notes:
Td: Average daily outdoor temperature
Tco: Comfort temperature

Based on equation 1, PCT of Banda Aceh is calculated by using the average daily outdoor temperature of 27.50C. The equation found that the predicted comfort temperature of Banda Aceh is 26.60C. From the predicted comfortable temperature range, we see that the average air temperature which is around 310C in Indrapuri mosque is above the standard.

Another tool for predicting the comfortable temperature is using the Olgyay's Bioclimatic chart which also considers the air velocity and relative humidity. Figure 9 shows that once the recorded data of air temperature (DBT0C) and the Relative Humidity (RH%) are traced on the Olgyay's Bioclimatic chart, it shows that the thermal performance is out of the comfort zone. The mosque with the sealed apertures of the second roof (Figure 10) and some wall apertures covered with cupboard and whiteboards (figure 9) are probably the reason for having low air speed. Based on the Olgyay's Bioclimatic chart, we see that to upgrade the thermal performance to be included in the comfort zone, the air movement must be increased up to 1 m/s. The worshippers approve this condition by installing fans to overall beams in the mosque to get more air movement (Figure 10). The previous design of the mosque with apertures without any seals on the top is believed to be a good way to circulate the hot air off from the top.

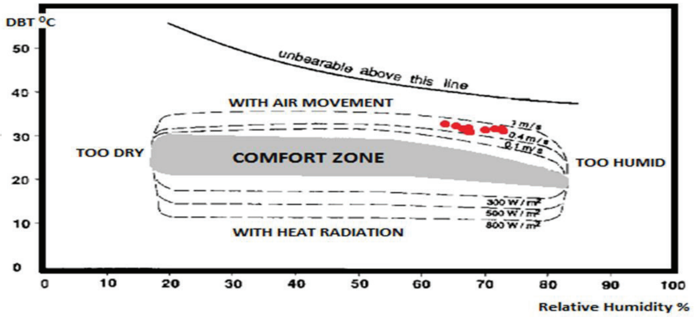


Figure 9: The Thermal PerformanceIllustrated in Olgyay's Bioclimatic Chart (Olgyay, 1992)

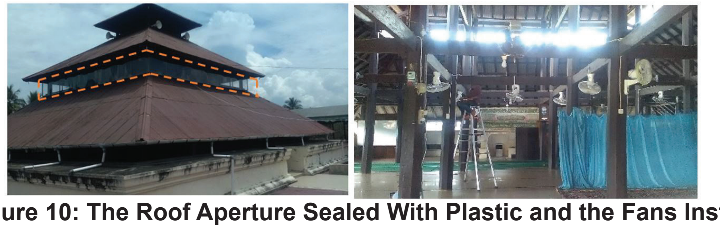


Figure 10: The Roof Aperture Sealed With Plastic and the Fans Installed and Attached to the Wooden Beams

Day Light Performance

Figure 11 shows that the overall room has sufficient daylight illuminance, which some areas such as A, D, G, H reach up to 2000 lux. Only area C and B suffer the lowest value of the illuminance. Area B at the qibla position that is facing northwest and C facing north have been partitioned with some cupboards and whiteboards which reduce the illuminance of the daylight which is around at 100-200 lux (Figure 12).

Figure 11: Daylight Illuminance (Lux) Received Inside Indrapuri Mosque

Figure 12: Wall Apertures Partitioned with Cupboards and Whiteboards

CONCLUSION

This study assessed the performance of thermal, room acoustic and daylight provision in Indrapuri mosque. Originally the mosque was built in lightweight construction applying the timber as the whole constructions, and rumbia leaf as the roof. After some decades, the mosque was modified. The aim was to get the mosque strengthened. The zinc sheet replaced the rumbia leaf as the roof material. The cement floor is coated with marbles. And the roof apertures were covered with plastic fiber. The study shows that those replacements cause some spatial discomforts such as high indoor thermal performance, high background noise and low luminance of daylight in some spots. However, some criteria such as reverberation time, sound pressure level and illuminance nicely meet the comfortable standard. This study shows that Indrapuri mosque meets the criteria of good room acoustics. However, the thermal performance is out of the comfortable zone due to the high relative humidity and air temperature and low air speed. The Olgyay's bioclimatic chart recommends that Indrapuri mosque should be provided with the air speed around 1 m/s to give the comfortable sensation. This can be achieved by removing the plastic fiber on the upper apertures to give more outlet for circulating the air out. Another option is to reduce the air temperature which is related to globe temperature that is influenced by the building material. Replacing back the leaf roof or any kind of materials with similar thermal properties as the roof material is one of the ways to reduce the air temperature. By planting the surrounding with high trees with thick leaves will also work to cool the micro climate. This study indicates that for conserving the building, installing new materials should be minimized to achieve the optimal spatial comfort. Alternatively, we could conserve the mosque by installing the materials or properties closed to the original one. Additionally, attaching information and supporting furniture should also be wisely managed to obtain not only the facade but also the indoor comfort.

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